SYMBOL TIMING RECOVERY METHOD FOR DMT-VDSL

BACKGROUND OF THE INVENTION

Field of Invention

5   The invention relates to a symbol timing recovery method used in DMT-VDSL and, in particular, to a method that uses the peaks and the company peaks in the frequency domain to calibrate the symbol timing.

Related Art

       The very high data rate digital subscriber line (VDSL) utilizes the discrete multi-tone

10   (DMT) technology.   In comparison with the commonly seen asymmetric digital subscriber line (ADSL), its transmission speed is higher (ADSL: 1.5-8M/0.3-2Mbps ，VDSL: 2-26M/2-16Mbps) but its transmission distance is shorter (ADSL: 4.8km ，VDSL: 1.5km). From the above-mentioned technical features, one sees that the ADSL technique is more suitable for an environment with users living over 1km away from the telecommunication

15   company.   The users can enjoy the ADSL service using the existing phone lines.   The VDSL technique is more suitable for an environment of community-type high-rise buildings.   Fibers are connected from the telecommunication company to the high-rise building, where the community shares the bandwidth and the each individual user connects to the hub using the VDSL technique. .

20   During data transmissions, the DMT-VDSL has to first encode the data and perform an inverse fast Fourier transform (IFFT).   Before transmitting the converted signals, each discrete multi-tone signal is added with a cyclic extension (CE) to avoid inter-symbol interference (ISI), echoes, or cross-talks during transmissions.   Once the receiving end receives the signals, it first removes the CE parts, performs a fast Fourier transform (FFT),

25   and decodes to recover the original data.   In this process, one has to accurately compute

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the boundary positions in order to remove the CE parts.

In the prior art, recovering the symbol timing in the time domain is achieved by utilizing the repeated data property of the CE's, where part of the rear data are copied to the front of the symbol and part of the front data to the end of the symbol after the IFFT.Therefore, when the receiving end gets a signal, the whole signal is delayed by N-samples, where N is equal to the DMT symbol length. Then, correlation is computed between the original signal and the delayed signal. The section with a high correlation is the boundary. However, the precision of this method is low in practice and it requires a lot of memory.

On the other hand, the method of recovering the symbol timing in the frequency domain is to extract a section of the received signal that is equal to the length of the DMT symbol arbitrary. Then, it is converted into the frequency domain using the FFT. The channel frequency response is computed in the frequency domain and converted back into the time domain to give the channel impulse response. Theoretically speaking, the channel impulse response has a peak response relative to the boundary of the DMT signal. Therefore, one can use this method to obtain the correct boundary position. The most commonly seen ADSL can use the above method to recover the symbol timing.

However, the VDSL is different from other transmission modes. During the VDSL training phase, the odd tone of the DMT symbol is used to transmit information to be exchanged between two VDSL transceivers. Therefore, when computing the channel frequency response, we cannot know all the band responses. This will result in two peak responses of equal height. In addition, when extracting a section of original symbols (including CE) and converting them into the frequency domain, if the extracted signal has two adjacent symbols both of them will generate peak responses. Combining the above two effects, one usually obtain four peak responses when using the conventional frequency domain symbol timing recovery method to compute the channel impulse response. Unfortunately, we cannot know which one is the correct peak response corresponding to the

symbol boundary.

The method used in the ADSL technique cannot be directly applied to the VDSL technique. The U.S. Pat. No. 6279022 compares a known transmission frequency-domain pattern and the received frequency-domain symbol and computes to obtain the location of the peak response, thereby determining the boundary. It uses primarily the fact that the receiver in the ADSL transmission can obtain in advance all the symbols the transmitter will send. However, the there is no way to obtain all the symbols in advance in the VDSL system. Therefore, the method does not apply here.

SUMMARY OF THE INVENTION

In view of the foregoing, the invention provides a symbol timing recovery method for the discrete multi-tone very high data rate digital subscriber line (DMT-VDSL). The method not only reduces the usage of memory, but also effectively recovers the VDSL symbol timing.

The disclosed method extracts from the received signal a sample equal in length to the symbol and converts the sample to the frequency domain. It further computes the channel frequency response, and then converts it back into the time domain. From the position of the channel impulse peak in the time domain, the method obtains the company peak at the position with one cycle extension from the channel impulse peak. Using the powers of the peak and the company peak, the method determines the position of the company peak. The position of the peak determines the correct peak response, from which the calibration displacement is obtained to recover symbol timing.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will become more fully understood from the detailed description given herein below illustration only, and thus are not limitative of the present invention, and wherein:

FIG. 1 is a schematic view of the extracted sample being converted into the frequency domain according to the invention;

FIGS. 2A and 2B are schematic views of the company peaks of the invention;

FIG. 3 is a schematic view of the extracted sample corresponding to the original symbol;

FIG. 4 is a schematic view of another embodiment of the invention;

FIG. 5 is a schematic view of the steps in the disclosed method; and

FIG. 6 is a schematic view of the simulated symbols being converted into the frequency domain.

DETAILED DESCRIPTION OF THE INVENTION

With reference to FIG. 1, the discrete multi-tone very high data rate digital subscriber line (DMT-VDSL) method extracts from a DMT-VDSL signal a sample with a length equal to the symbol length N and converts it to the frequency domain. If the extracted sample crosses two adjacent symbols, the computed channel impulse response should have four peak responses because both the odd tone and the even tone of the VDSL contain specific information. Therefore, an extra peak response set is obtained. The powers of the two peak response sets are equal in magnitude and the distance is a fixed quantity N_{SC} (N/2). Each peak response set has two peak responses because the extracted sample 14 crosses two adjacent symbols 13 (see FIG. 3). The powers of the two peak responses differ for different extraction lengths, but the distance is always the length of CE, L_{CE}.

Please refer to FIG. 6 that shows the simulated channel impulse responses. Each plot therein has a corresponding time delay. The dashed line represents the DMT symbol boundary in reality. The peak response labeled by a circular dot is the actual peak response. The other equal peak response is produced by the reason described above. Independent of the relation between the extraction position and the boundary position, there

are at least two peak responses. Therefore, one only needs to consider half of the channel impulse responses in order to know which peak response is true. From the true peak response position, one can know the symbol boundary position and make a calibration of the displacement $\triangle$ (see FIG. 3).

5   Take the first half region (0~N/2) as an example. As shown in FIGS. 2A and 2B, if the peak 11 is in the first quarter part (0-N/4) and it is a false peak response, a company peak 12 follows it at length of L_{CE} (see FIG. 2A). On the other hand, if the peak 11 is in the second quarter part (N/4~N/2), a company peak 12 is in front of it at a length of L_{CE} (see FIG. 2B) and the peak 11 is the true peak response. The power of the company peak

10   12 divided by the power of the peak 11 has to be greater than a predetermined power ratio v. The power is the height in the plot. It is computed using the formula:

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P(L) = \begin{cases} \sum_{i=L}^{L+L_{CP}-1} h(i)^2 & \text{if } L + L_{CP} \leq N \\ \sum_{i=L}^{N-1} h(i)^2 + \sum_{i=0}^{L+L_{CP}-1-N} h(i)^2 & \text{otherwise} \end{cases}
$$

where h(i) is the result after inverse fast Fourier transform (IFFT) into the time domain.

      To compute the power ratio v, please refer to FIG. 3. The extracted sample 14 crosses

15   two adjacent symbols 13 and has a displacement $\triangle$ from the boundary. Therefore, the powers contributed by the two symbols 13 are $\dfrac{N + L_{CE} - \Delta}{N}$ and $\dfrac{\Delta - L_{CE}}{N}$, respectively.

Putting $\Delta = N_{SC}/2 = N/4$ into the above formula, one obtains $\dfrac{0.75N + L_{CE}}{N}$ and

$\dfrac{0.25N - L_{CE}}{N}$. The amplitudes are roughly 3:1 and the powers are thus 9:1. Therefore,

one can define the power ratio to be 0.1.

20   In summary, one can obtain that when $L_0 \geq N_{SC}/2$ (L_0 being the position of the peak

11) the company peak 12 at the check position $L_1 = L_0 - L_{CE}$ is:

$$FLAG = \begin{cases} TRUE & \text{if } P(L_1) \geq P(L_0) * v \\ FALSE & \text{otherwise} \end{cases} \quad \text{(see FIG. 2A)}$$

In other words, when the power of the company peak 12 satisfies the above equation, the corresponding peak 11 is the true peak response; otherwise, it is a false one. (In the above equation, FLAG represents a condition, TRUE represents true, and FLASE represents false.) When $L_0 < N_{SC}/2$, the company peak 12 at the check position $L_1 = L_0 + L_{CE}$ is:

$$FLAG = \begin{cases} FALSE & \text{if } P(L_1) > P(L_0) * v \\ TRUE & \text{otherwise} \end{cases} \quad \text{(see FIG. 2B)}$$

Its determination is the same as before. One thus sees that the position of the true peak response τ is: $\tau = \begin{cases} L_0 & \text{if } FLAG \text{ is } TRUE \\ L_0 + N_{SC} & \text{otherwise} \end{cases}$. The displacement $\triangle = \text{N-} \tau$.

However, in the case where CE occurs in both the front and back, as shown in FIG. 4, CE contains a cyclic prefix (CP) and a cyclic suffix (CS). Then the displacement $\triangle$ is corrected as:

$$\Delta = \begin{cases} N - \tau & \text{if } \tau \geq N_{SC} \\ N_{DMT} - \tau & \text{otherwise} \end{cases}$$

where $N_{DMT} = N + CE - \beta$ and β represents the overlapped length of two adjacent DMT symbols defined by the VDSL standards.

The flowchart of the invention is shown in FIG. 5. With further reference to FIG. 3, when a mixture of a signal and CE is received, the method extracts from it a sample equal in length to the symbol (step 501). The sample is converted into the frequency domain using the Fourier transform. The method then computes the channel frequency response in the frequency domain (step 502). The signal is the converted back into the time domain as the channel impulse response, obtaining at least two peaks 11 (step 503). The distance

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between the two peaks is half the symbol length N_{SC}, as shown in FIG. 1. A peak is selected according to the method described above. According to the position and power of the peak 11, the method determines a company peak 12 (step 504). From the powers, the method determines whether the selected peak 11 is the true peak response (step 505). The true peak is then used to calibrate the sample position (step 506).

In practice, if the extracted sample is very close to the position of CE (i.e. when τ approaches N), using τ for calibration will result in an error that only makes the calibrated sample away from the position but not to the correct position. Therefore, one can further compute and calibrate another time to find the optimized value. However, if each time the method has to determine whether τ approaches N, it results in additional memory waste and complicates the algorithm. Therefore, the invention can be modified to perform the determination twice. The method thus first checks whether it is the first determination (step 507). If it is, then step 501 is performed again. If it is the second time, then the symbol timing of the symbol can be recovered directly (step 508).

Certain variations would be apparent to those skilled in the art, which variations are considered within the spirit and scope of the claimed invention.